Chapter 9. Research and Analysis

The SEU Research and Analysis (R&A) program provides opportunities to develop new ideas, concepts, and methods. These are crucial to the health of the SEU theme and often form the basis for new mission concepts. It has strong university involvement, providing the additional return of training graduate students and instrument builders for future space missions. Veterans of the R&A program become Principal Investigators of flight missions, major instrument builders, or sometimes even astronauts!

There are two major components to R&A: (1) experimental research (including hardware development, suborbital flights, and laboratory astrophysics), which creates new tools, and (2) interpretive research (theory, observations, and data analysis), which makes discoveries and predicts new directions. We consider each in turn.

"Progress in science depends on new techniques, new discoveries and new ideas, probably in that order."
—Sidney Brenner [Nobel Prize, 2002]

Experimental Research: Creating the Tools of Investigation

The R&A experimental program develops novel tools for new and better science. Ideas are tested in laboratory demonstrations and suborbital flights by balloon or rocket. This provides a cost-effective shortcut to mission-readiness for new technology.

Hardware Development

The R&A program is the cradle for the technology of SEU's future missions. The R&A hardware program takes development to the proof-of-concept level. At the point where engineering issues dominate, the SEU's Technology Line takes over. Mission-specific funding carries development to completion. This three-stage approach is cost-effective, encourages innovation, and minimizes risk.

The candidate detectors for Constellation-X were all born in the R&A program. These detectors have flown on ASCA and the Chandra X-ray Observatory and are slated to fly on Astro-E2 and Swift. The R&A program also developed the specialized bolometers that will fly on Herschel, Planck, and several suborbital missions. The COBE and MAP detectors are the fruits of previous R&A development.

Future missions will need innovative optics. High-resolution segmented optics, such as those used on ASCA, were first developed within the R&A program. Multilayer coatings for hard X-ray optics are currently under development. Nanotechnology developed in the R&A program enabled high-resolution spectroscopy for the Chandra observatory and will enhance high-resolution imaging optics, technologies critical for Constellation-X and an X-ray Black Hole Imager.

Suborbital Program

The Suborbital Program produces exciting scientific results while also serving as a testbed for hardware and a training ground for future instrument and mission scientists. The BOOMERanG and MAXIMA balloon payloads provided the best power spectra for the CMB anisotropies prior to the advent of MAP. Combined with measurements of large scale structure, they revealed a Universe that is about 70 percent dark energy, one of the most exciting new results in cosmology.

The program features quick turnaround and low launch cost, essential for space-qualifying otherwise risky forefront technologies. Balloon and rocket flights test new capabilities vital to mission development. GLAST, FUSE, Chandra, XMM, Astro-E2, COBE, MAP, Herschel, and Planck have benefited from such efforts. For Constellation-X, balloon experiments carry CdZnTe detectors and hard X-ray optics, and X-Ray microcalorimeters were first demonstrated on rocket payloads. Future suborbital testing will include lightweight and deployable optics, cryocoolers, and detectors.

Suborbital investigations have short lead-times and are ideal for quick response to new discoveries. For example, balloon flights with gamma-ray detectors developed under the Research and Analysis budget made time-critical observations of supernova 1987A.

The suborbital program will soon support Ultra-Long Duration Balloons, which can economically carry payloads of several thousand pounds for long periods to a near-space environment. These balloons can fly at any latitude and have active trajectory control and advanced recovery systems. The potential of this program has been widely recognized and explicitly recommended by the NAS AASC decadal report.

Laboratory Astrophysics

Combining laboratory experiments, modeling, and theoretical calculations, the Laboratory Astrophysics program provides scientists with the fundamental knowledge and reference data they need to link raw observation and meaningful, scientific conclusions. The program explores a tremendous breadth of topics, from the very coldest regions deep in dark molecular clouds to the extraordinary heat around supermassive black holes. It supports NASA's space missions from conception to completion, defining mission parameters and supporting post flight analysis.

Laboratory Astrophysics includes work on atomic and molecular properties needed to interpret astrophysical spectra. NASA programs and missions require critically compiled stable databases of these properties, available online. The highest priorities for the Laboratory Astrophysics program have been identified in the *Summary of Laboratory Astrophysics Needs* white paper from the 2002 Laboratory Astrophysics Workshop.

The Chandra X-ray Observatory and XMM-Newton have demonstrated the power of high resolution spectroscopy in X ray astronomy, and missions such as Astro-E2 and Constellation-X will build on this foundation. The level of detail now in grating spectra has uncovered discrepancies between observed cosmic X-ray line emission, laboratory measurements, and theoretical calculations. Current models of weak or blended features, such as the complex iron-line region, are often inadequate for interpreting observed cosmic

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X-ray emission. To unleash their diagnostic power, these discrepancies must be resolved—through sound laboratory and theoretical studies. Laboratory measurements are essential to interpretation of observations at other wavelengths, too. The rich infrared-submillimeter band requires laboratory measurements of the formation of solid grains and ices, and precise wavelengths for diagnostic spectral lines.

Theory, Observations, and Data Analysis: Reaping the Benefits of Investment

Space-based experiments must be firmly rooted in ground-based observation and theoretical calculation. Only then can data analysis close the loop that allows NASA to realize the goals of the SEU program.

"Those who dream by day are cognizant of many things which escape those who dream only by night."
—Edgar Allen Poe

Theory

Theoretical studies establish the framework within which scientific questions are asked. They allow scientists to interpret data and make the predictions that drive mission design.

Predictions of the spectrum and anisotropy of the Cosmic Background Radiation motivated COBE, MAP, and Planck. The requirements for JWST have been guided by cosmological and stellar evolution theory, and those for GLAST by the theory of particle acceleration and photon interactions in relativistic sources and the Universe. Theoretical work showed that high time resolution X-ray monitoring could probe the strong gravity around black holes and neutron stars, motivating RXTE. Theorists have shown how the X-ray emission lines in accreting black holes can provide unique tests of the general theory of relativity, motivating, and shaping Constellation-X.

Present and planned missions are the fruits of bold theoretical investment in the 1980s and 1990s. Today's theoretical ideas are bolder still. The R&A program is NASA's place to nurture these visions and ensure a vital future.

Ground-based Observations

Ground-based observations contribute to the development of techniques and instruments in support of space missions.

In addition, great scientific return often comes from the combination of observations across the electromagnetic spectrum. Some of these are most efficiently performed from the ground. Ground-based optical studies of the afterglows of gamma-ray bursts reveal the distance to and the nature of these sources. Nonthermal emission from active galactic nuclei covers the entire spectrum from radio to gamma-ray. Ground-level observations of the atmospheric Cherenkov radiation from gamma rays of the highest energies will complement observations from GLAST. Emissions in various wavelengths from the vicinity of massive black holes correlate on a time scale of days, demanding contemporaneous observation. Ground-based observations will support gamma-ray burst studies by Swift, AGN observations by GLAST, black hole studies by LISA and the Black Hole Finder Probe, and LISA's white dwarf studies. The Dark Energy Probe will make use of spectroscopy by larger telescopes on the ground.

Ground-based observations should be coordinated with the National Science Foundation to ensure that the highest priority research is conducted most cost-effectively.

Archival Research

As data from previous and ongoing NASA missions mounts, so too does the value of archival research. Data mined from NASA's archives have led to a better understanding of important and interesting astrophysical phenomena. These archives are growing rapidly in both content and diversity. More sophisticated software tools would support searches spanning multiple archives, facilitating valuable scientific investigations long after an observatory has ceased operation. The proposed National Virtual Observatory, to be developed jointly by NASA and NSF, would provide this capability.

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